# Magnetic Device Design' and Evaluation Capabilities at JPL

Dr. Romney R. Katti
Center for Space Microelectronics Technology
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

May 15,1995

# Presentation overview

- Magnetic device development paradigm.
- Magnetic device design and simulation capabilities at JPL.
- Magnetic device experimentation and observation capabilities at JPL.
- Standardization of magnetic device development tools and processes.
- Potential applications in future space missions.
- Conclusions.

# A Device Development Paradigm

- Device development uses cycles of design, fabrication, experimentation, and analysis.
- Device design invokes conceptual and calculable design processes, including analytical and simulated calculations, based on available materials, fabrication processes, and test data.
- Experimentation, testing, and characterization are used to demonstrate device performance, and to validate fabrication and design processes.

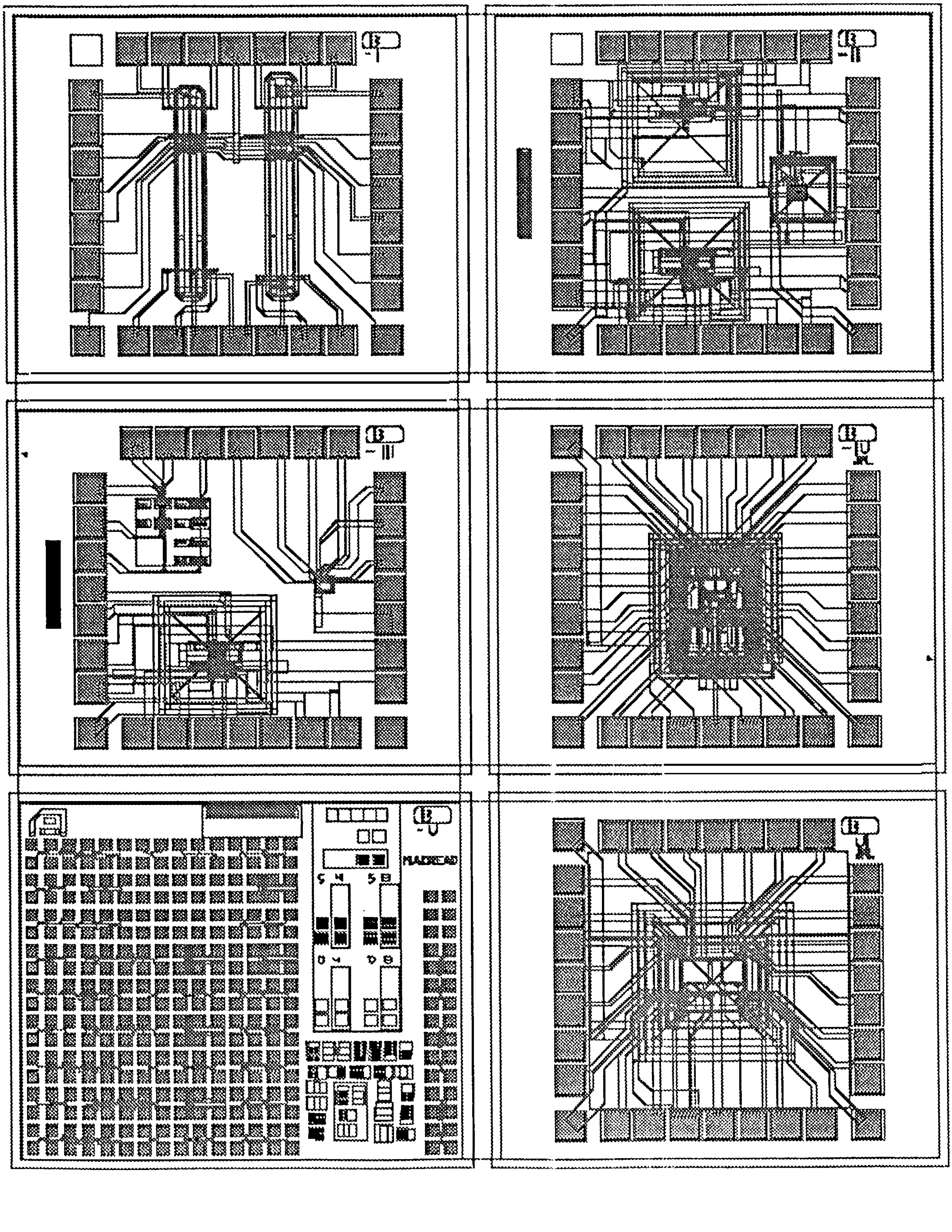
# JPL Design Capabilities

- Device Layout.
- Computer simulations:
  - » Magnetic field computation.
  - » Distributed Wall Modeling.
  - » Micromagnetic Modeling.

# Magnetic Device Layout Representation

- Magnetic Device Layers:
  - » **Conductors.**
  - » **Insulators and Dielectrics.**
  - » **Vias.**
  - » **Permeable magnetic layers.**
  - » **Magnetoresistors.**
  - » **Permanent magnets.**
  - » **Implantation.**
  - » **Stress Layers.**
  - » **Mirrors.**
- Output formats:
  - » CIF.
  - » GDS-II.

Cell: bchip File: BCHIP040795 Date: 11 Apr 95 Tanner Tools L-Edit™/Macintosh
Cell bounds: 153000 x 195000 Units = 7650 x 9750 Microns
This view: 164528 x 217582 Units = 8226 x 10879 Microns



# Magnetic Field Computation

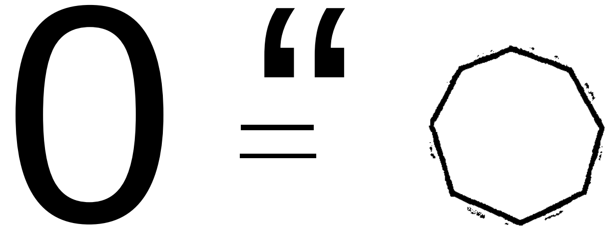
- Magnetic field computation:
  - » Custom computer programs:
    - – Magnetic field induced by currents.
    - – Magnetic field induced by magnetization and its divergence.
  - » Commercial software.

# Distributed Wall Model

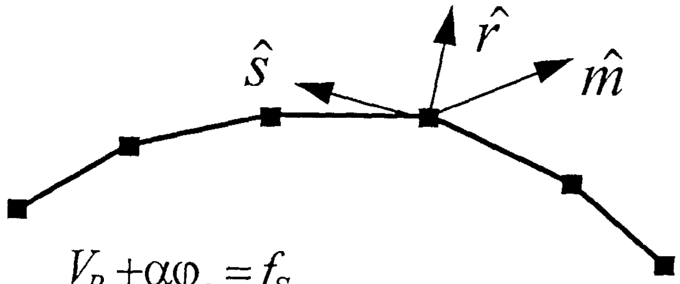
- Simulate static and dynamic domain wall motion in a magnetic material.
- Represent a domain wall by a set of wall points.
- Model material parametrically.
- Apply equation of motion at wall points to determine domain wall dynamics.
- Use on workstations or personal computers to simulate dynamics up to millimeter dimensions for up to millisecond durations.
- Provide graphical and file-input user interfaces to facilitate initiating, visualizing, and analyzing case studies.

# Micromagnetic Devices Group
# DWM: Overview

- **Approximate wall with a polygonal segment.**



- **Equations of motion for wall points:**




$$V_R + \alpha\varphi_a = f_S$$

$$\alpha V_R - \varphi_a = f_R$$

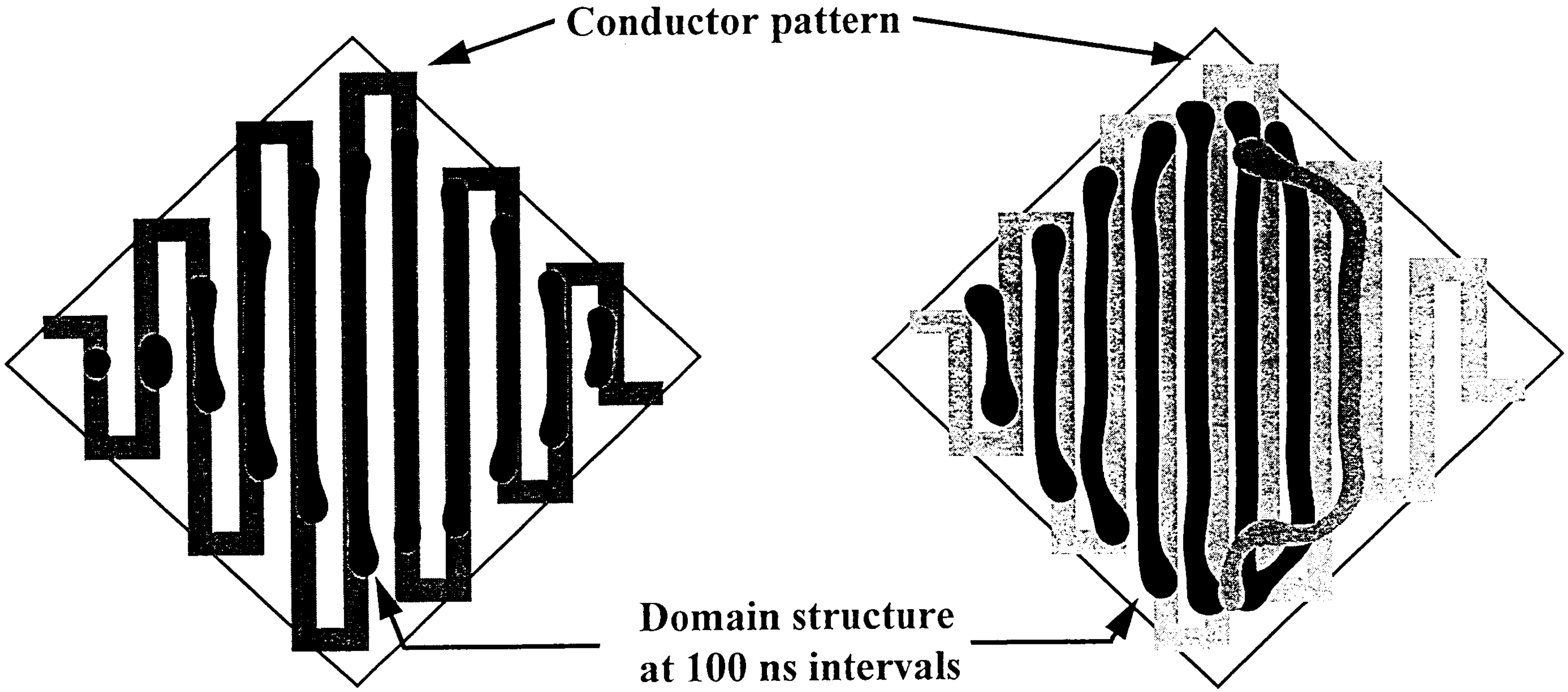
$$f_S = \frac{1}{2}\left(\sin 2\varphi_w + 2q\frac{\partial^2 \varphi_a}{\partial S^2}\right)$$

$$f_R = -\frac{q}{\rho} - \frac{1}{2}\frac{\partial}{\partial S}\sin 2\phi_w + (H_D - H_A)$$

# Micromagnetic Devices Group
# Sample DWM Result

**Normal Operation of VBL Expander/Detector Region**

**Failure Mode of VBL Expander/Detector Region**

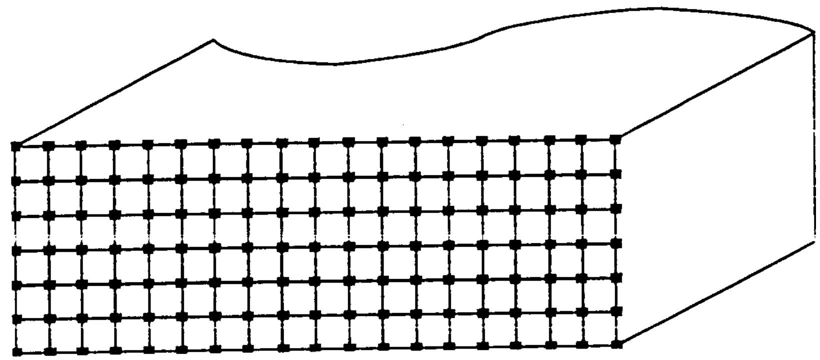


# Micromagnetics Model

- Simulate statics and dynamics of magnetization in discretized cells in a magnetic material.
- Represent domain wall as a strip of reversing magnetization.
- Solve the Landau-Lifschitz-Gilbert equation of motion locally to determine magnetization dynamics.
- Use on supercomputers to simulate dynamics at submicron nanoscales for submicrosecond durations.
- Provide graphical and file-input user interfaces to facilitate initiating, visualizing, and analyzing case studies.

# Micromagnetic Devices Group
## Micromagnetics: Overview

■ **Low level material modeling which accounts for changes in the magnetization on the order of 10nm.**



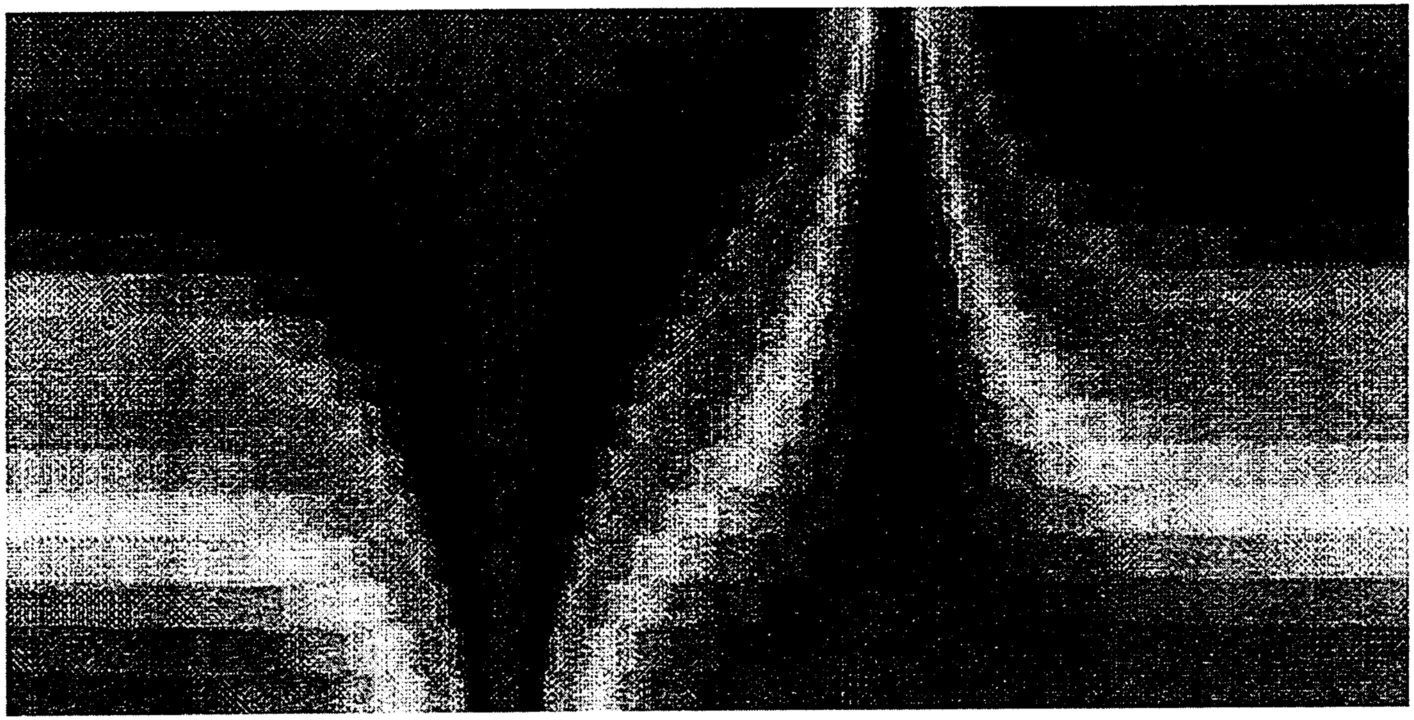
$$\dot{\hat{m}} = \frac{\gamma}{(1+\alpha^2)}(H \times \hat{m}) + \alpha(\hat{m} \times (H \times \hat{m}))$$

$$H^{total} = H^{anis} + H^{exch} + H^{demag} + H^{external}$$

# Micromagnetic Devices Group
# Sample Micromagnetic Result

## ■ Structure of a $2\pi$ VBL in garnet material.

(color shows component of magnetization perpendicular to wall surface)

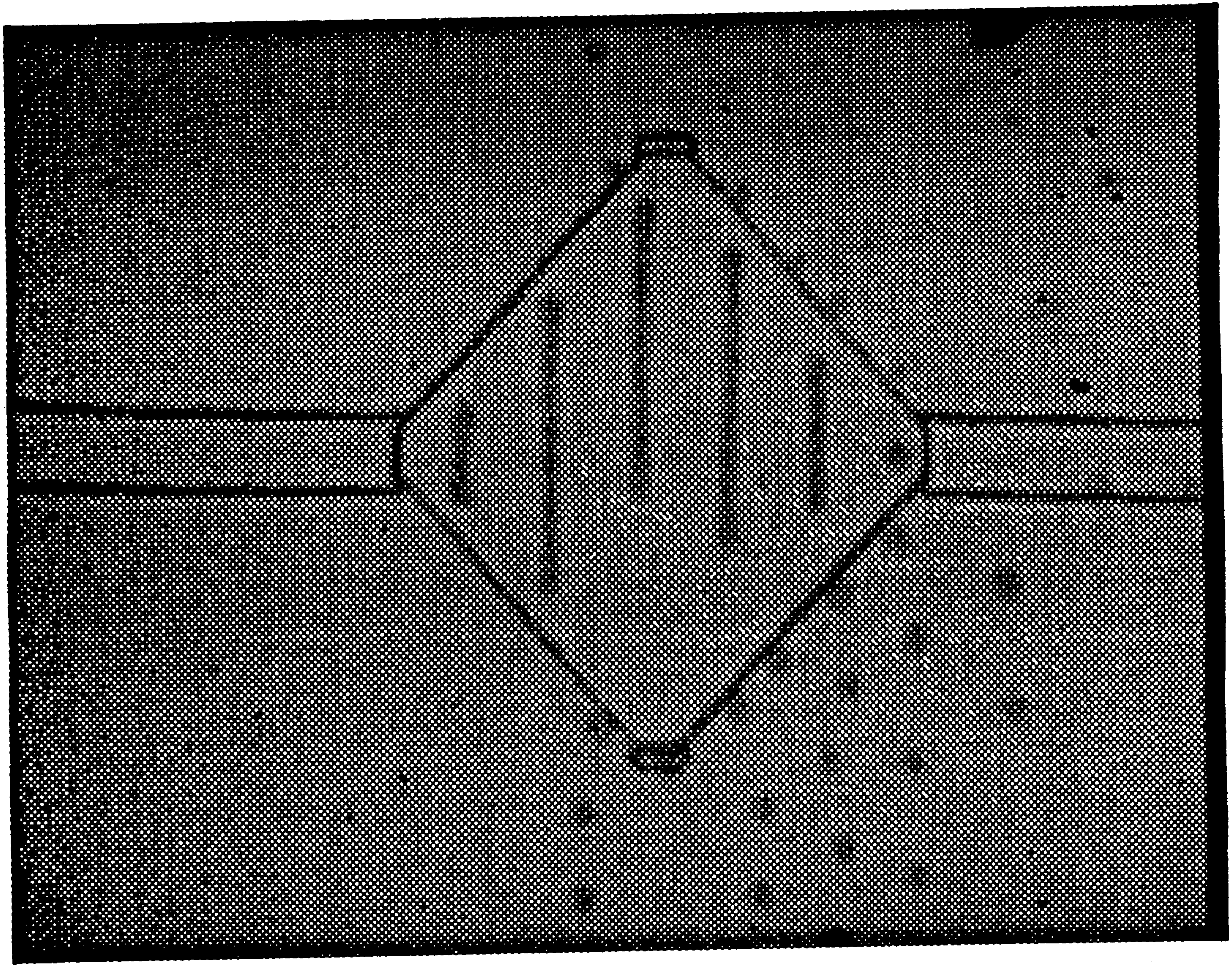


# JPL Experimentation **Capabilities**

- Electro-magneto-optic test systems:
  - » **Continuous illumination microscopy.**
  - » **High-resolution sampling microscopy.**
- Magnetoresistance characterization system.
- Electrical wafer-level probing systems.
- Logic analyzers.
- Characterization:
  - » **SEM, TENI, AFM, XRD, etc.**
- Spaceflight Experiments.

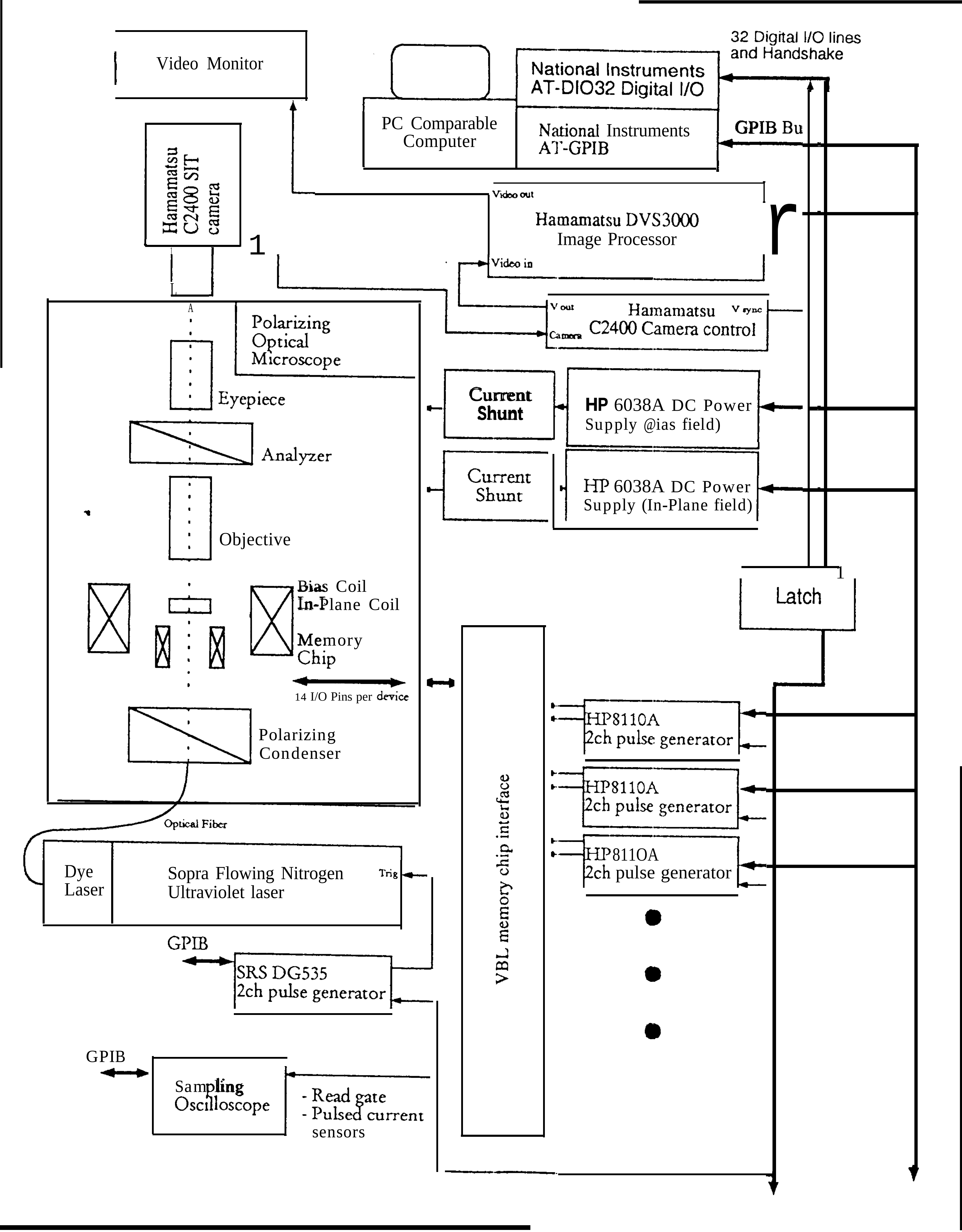
# Electro-magneto-optic testing: Continuous illumination

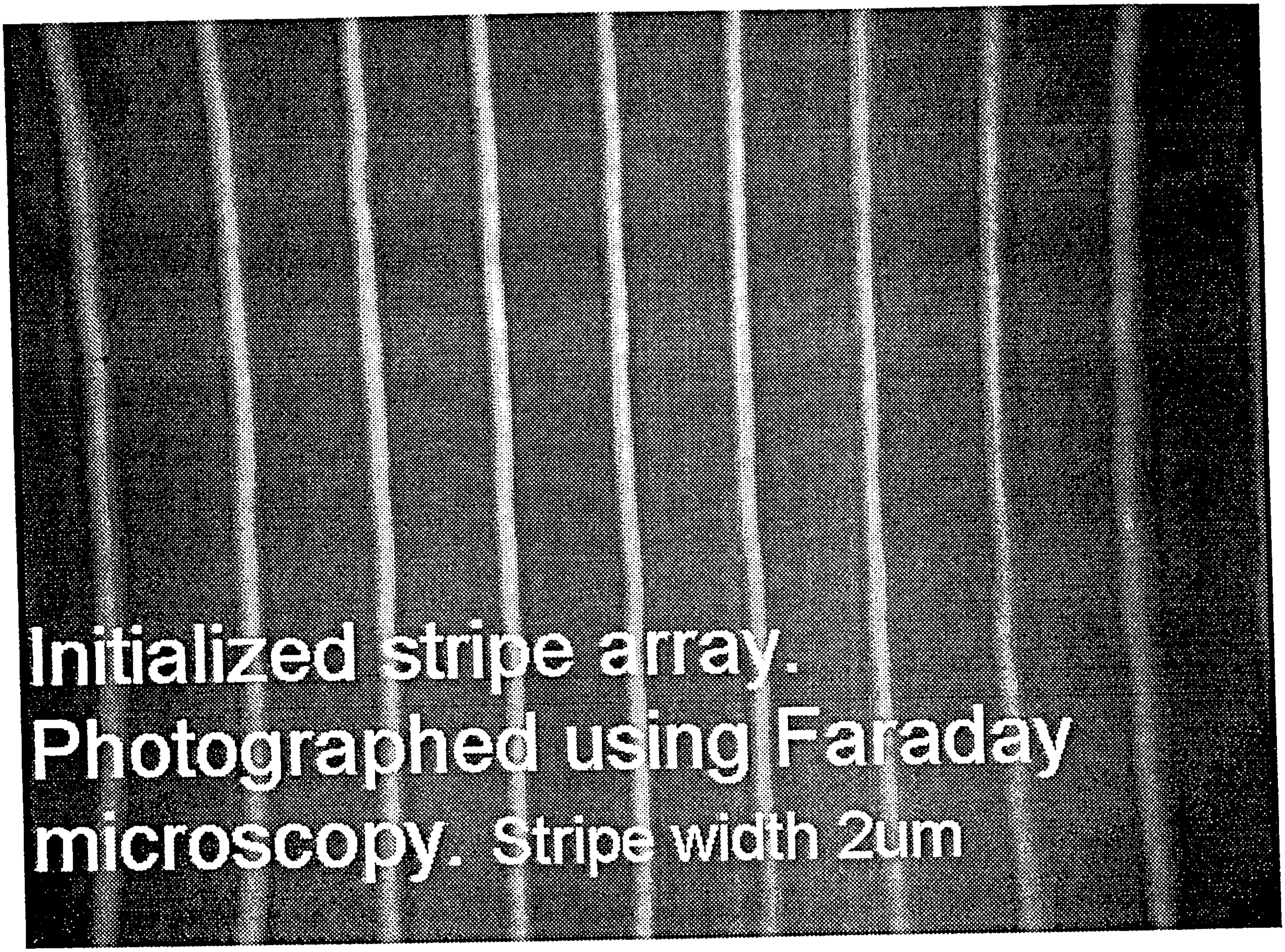
- Observe domains, domain walls, and domain wall structure in magnetic devices and films in transmission and reflection.
- Observe magnetic domain characteristics statically and through time-averaging, using optical and opto-electronic observation.
- Use continuous illumination to maximize image signal-to-noise ratio:
  - » **High photon density.**
  - » **Signal averaging.**
- Operate device subject to a variety of magnetic fields under computer control:
  - » **Derive AC and DC fields from on-chip conductors; with in-plane and out-of-plane components.**
  - » **Derive AC and DC fields from off-chip coils, magnets, and electromagnets; with in-plane and out-of-plane components.**



# Electro-magneto-optic testing: Sampling microscopy

- Observe domains, domain walls, and domain wall . structure in magnetic devices and films in transmission and reflection.
- Observe magnetic domain characteristics in a sampling mode, using optical and opto-electronic observation.
- Use laser stroboscope and image processing to determine repetitive magnetization dynamics with approximately 10 ns event resolution:
  - **Perform flash microscopy using high-power pulse laser and SIT camera.**
  - Use frame-grabbing, **averaging, and subtraction to observe** magnetization **dynamics.**
- Operate device subject to a variety of magnetic fields under computer control:
  - **Derive AC and DC fields from on-chip conductors; with k-plane and out-of-plane components.**
  - **Derive AC and DC fields from off-chip coils, magnets, and electromagnets; with in-plane and out-of-plane components.**

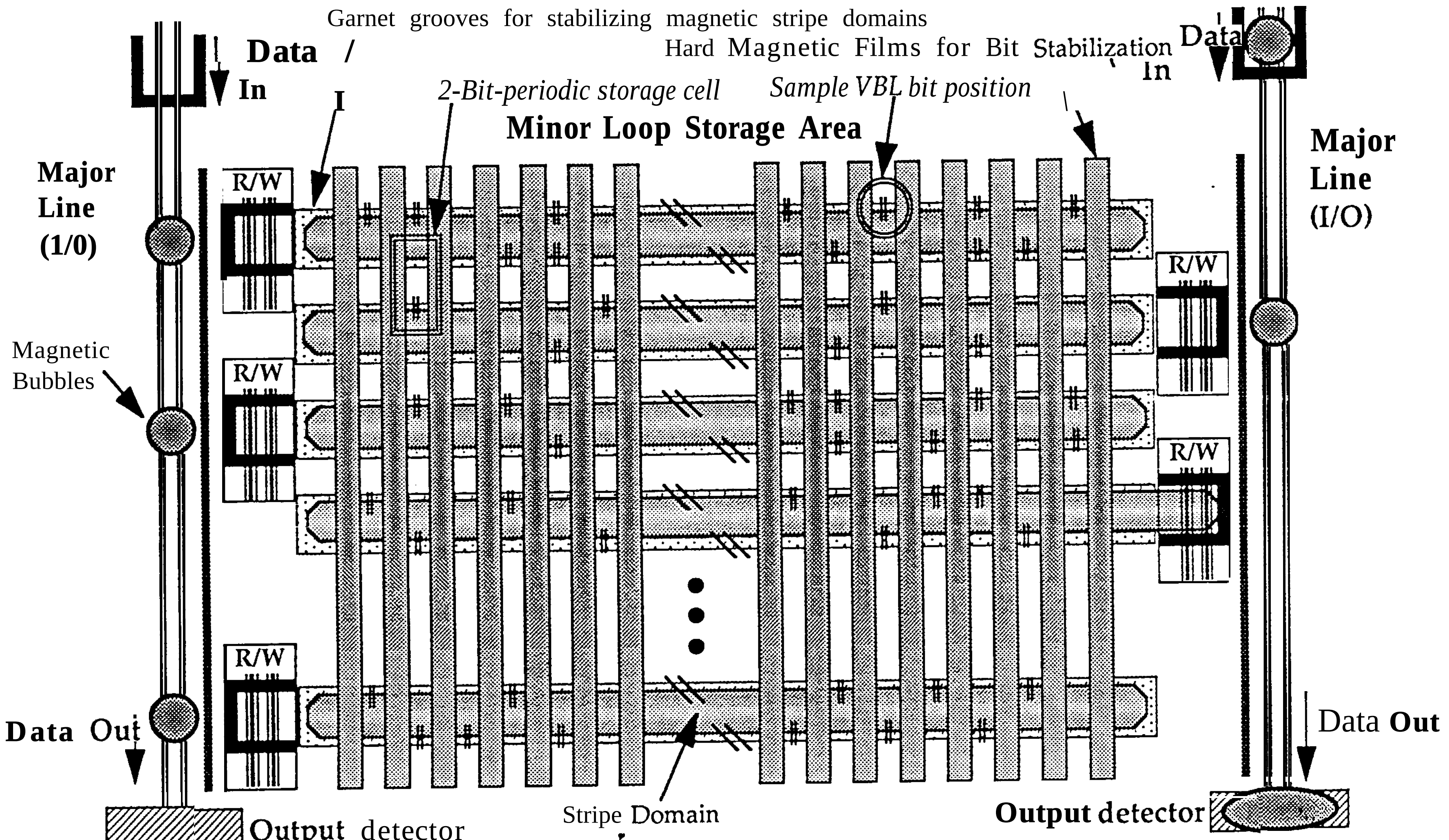

Video Monitor
PC Comparable Computer
National Instruments AT-DIO32 Digital I/O
National Instruments AT-GPIB
32 Digital I/O lines and Handshake
GPIB Bu
Hamamatsu C2400 SIT camera
Video out
Hamamatsu DVS3000 Image Processor
Video in
V out
Camera
Hamamatsu C2400 Camera control
V sync
Polarizing Optical Microscope
Eyepiece
Analyzer
Objective
Bias Coil
In-Plane Coil
Memory Chip
14 I/O Pins per device
Polarizing Condenser
Current Shunt
HP 6038A DC Power Supply @ias field)
Current Shunt
HP 6038A DC Power Supply (In-Plane field)
Latch
VBL memory chip interface
HP8110A 2ch pulse generator
HP8110A 2ch pulse generator
HP811OA 2ch pulse generator
Optical Fiber
Dye Laser
Sopra Flowing Nitrogen Ultraviolet laser
Trig
GPIB
SRS DG535 2ch pulse generator
GPIB
Sampling Oscilloscope
- Read gate
- Pulsed current sensors


Initialized stripe array.
Photographed using Faraday
microscopy. Stripe width 2um

# Potential Application to Spaceflight

- Opportunities exist for demonstrating and validating new technologies in space to enable new space missions:
  - » Performance in space and Performance determined in space testing provides additional experimental data on magnetic device operation characteristics.
  - » Performance in space provides additional technology validation.
  - » Space applications provide requirements which have similarities to and differences from commercial requirements.
  - » The potential for addressing viability in space applications may be promising, such as through NASA's "New Millenium" program.

# A Sample Magnetic Device under Development: A VBL Data Storage Chip




R.Katti 5/15/95 p. rk-13

JPL/CSMT

# Device Development Environments

- Simulation tools, emulation tools, and statistical models written at a variety of levels support semiconductor device development.
- Standard layout descriptions (e.g., CIF) and standardized fabrication processes (e.g., MOSIS) support rapid prototyping and packaging of semiconductor devices.
- A variety magnetic design tools and simulation tools exist for designing magnetic devices, such as electromagnetic field computation tools and Landau-Lifschitz-Gilbert equation solvers.
- Magnetic **materials and device fabrication capabilities exist in a variety of universities, laboratories, and** corporations
- Standardization of magnetic device descriptions and fabrication capabilities could greatly assist magnetic device development in analogy to that realized for semiconductor devices.

# Conclusions

- Magnetic design and testing capabilities exist which can and are being used to develop and to investigate new magnetic devices.
- The possibility of investigating new device technologies for space applications offers the potential opportunity for validating new technologies while enabling and enhancing future space missions.
- An opportunity exists to define and to standardize magnetic device design tools, design layout descriptions, and fabrication processes to simplify and expedite magnetic device development.